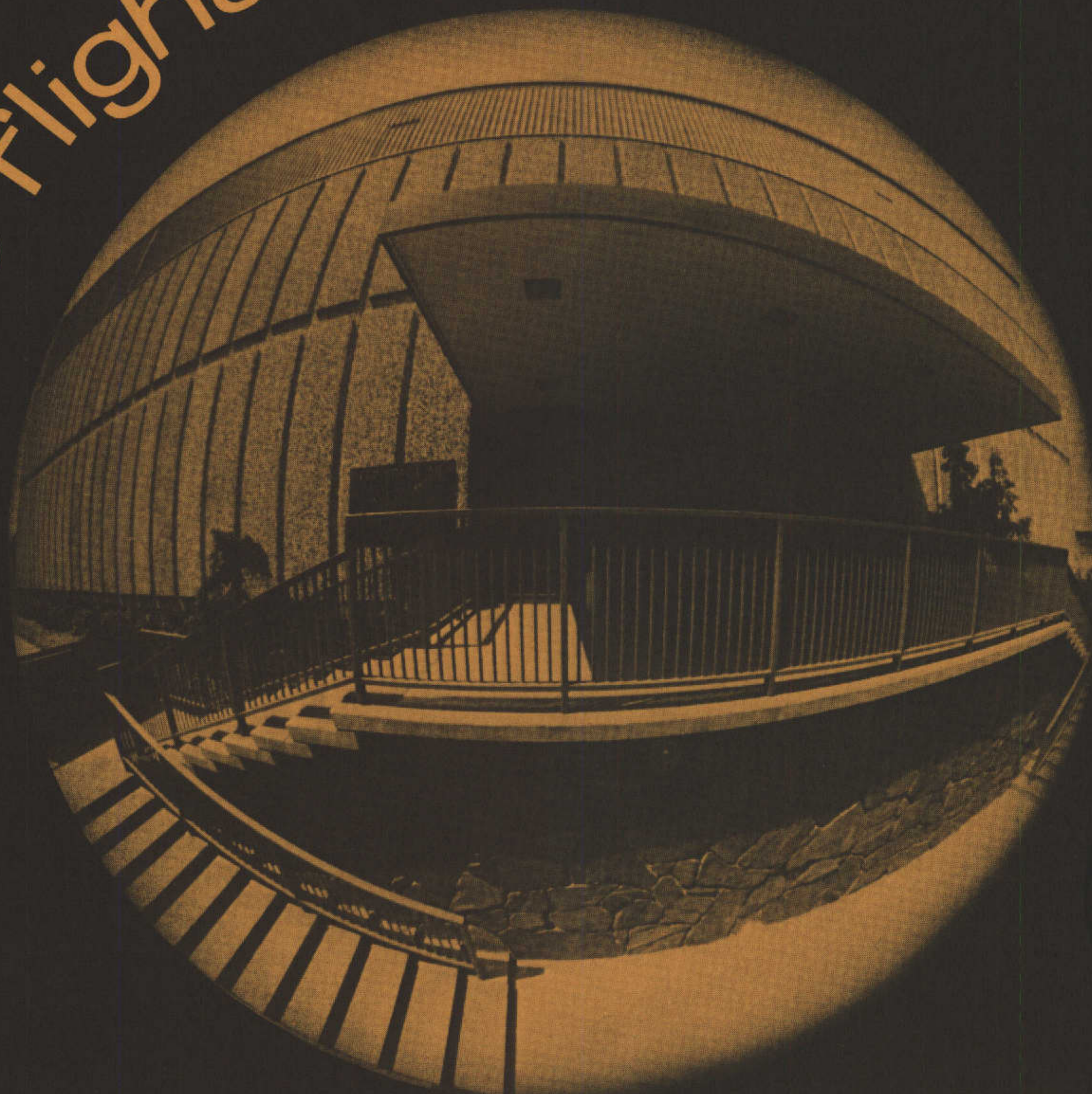
jpl

space flight operations

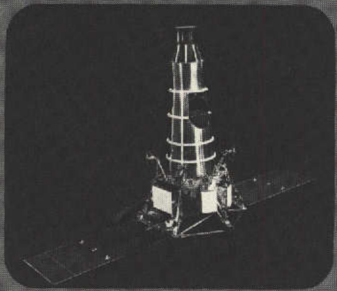
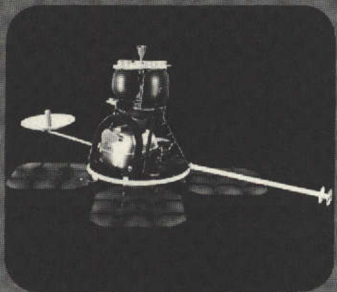
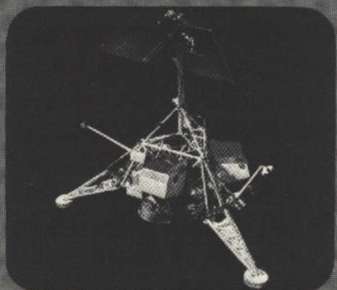
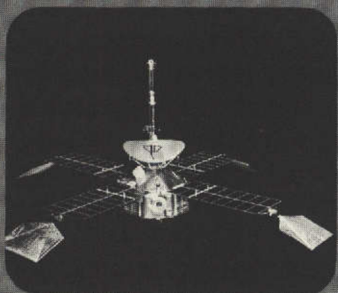
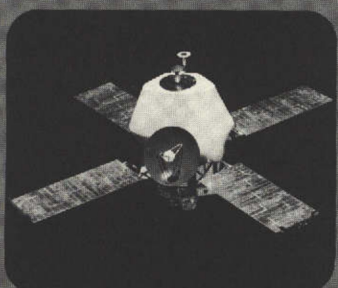


exploring the solar system

Under contract to the National Aeronautics and Space Administration (NASA), the Jet Propulsion Laboratory (JPL) of the California Institute of Technology manages and operates the facilities required to support unmanned spacecraft in missions to the Moon, the planets, and beyond.

Supporting every NASA flight is the ground system, which enables engineers to command the spacecraft and to interpret its signals. The Jet Propulsion Laboratory has pioneered the development of many important elements of this ground data system, which is used to communicate with the spacecraft many millions of miles from the Earth. In 1958, JPL established a worldwide network of tracking stations to receive data from the United States' first Earth-orbiting satellite, Explorer 1. This network, which includes stations in California, Spain, and Australia and is now known as the Deep Space Network (DSN), can communicate with spacecraft traveling to targets as close as the Moon or as far away as the outer reaches of the solar system. The Mission Control and Computing Center (MCCC) at JPL in Pasadena, California, houses the mission control personnel and the computer facilities that command and control spacecraft in flight. Communications between the Mission Control and Computing Center and the tracking stations, as well as communications among the stations, are the responsibility of the DSN Ground Communications Facility, which connects all parts of the ground system with telephone, teletype, and high-speed data lines.

During the 1970s, these facilities have supported and will support a variety of explorations. A Mariner spacecraft was the first to orbit a planet other than Earth. A Pioneer spacecraft will fly past Jupiter and on into space, as the first man-made object to leave the solar system. A Mariner spacecraft will fly by both Venus and Mercury. Two Viking spacecraft (Mariner-type orbiters coupled with landers) will study the planet Mars.

missions supported

First used in 1964 and subsequently improved and expanded several times so that it now encompasses two large buildings, the Mission Control and Computing Center has supported five major mission families with a total of over 20 successful flights:

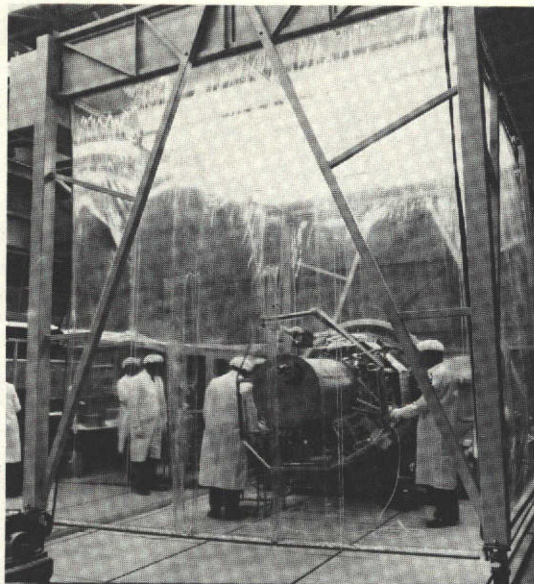
RANGER: Hard-landing missions to various areas of the Moon to take the first closeup photographs of another body in space.

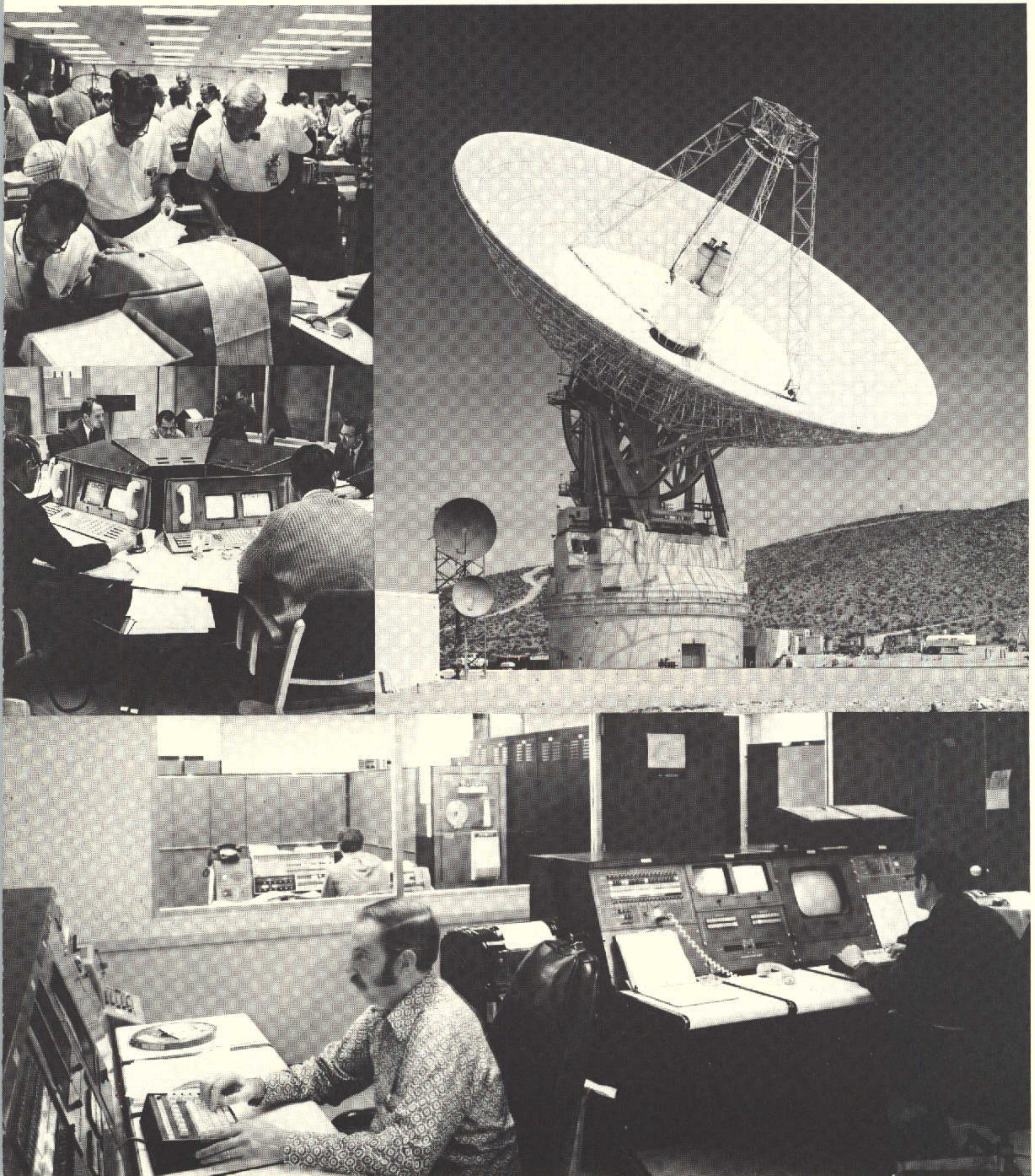
LUNAR ORBITER: Lunar missions to take television pictures of the Moon from a spacecraft in lunar orbit.

SURVEYOR: Soft-landing photographic missions to the Moon to collect information concerning the lunar surface and to conduct tests in support of the Apollo Program.

MARINER: Flyby missions to Mars in 1964 and 1969 and to Venus in 1967, as well as a Mars orbital mission in 1971. The purpose of the earlier Mars missions was to carry out preliminary studies of the planet's atmosphere and environment and to photograph limited areas of the surface. Mariner 1971 studied the dynamic characteristics of Mars from orbit, providing extensive photographic coverage. Both the Venus and the Mars Mariners performed scientific experiments at the planets and in interplanetary space.

PIONEER: Spacecraft probes for penetration into our solar system to learn more about solar flares and other deep space phenomena.





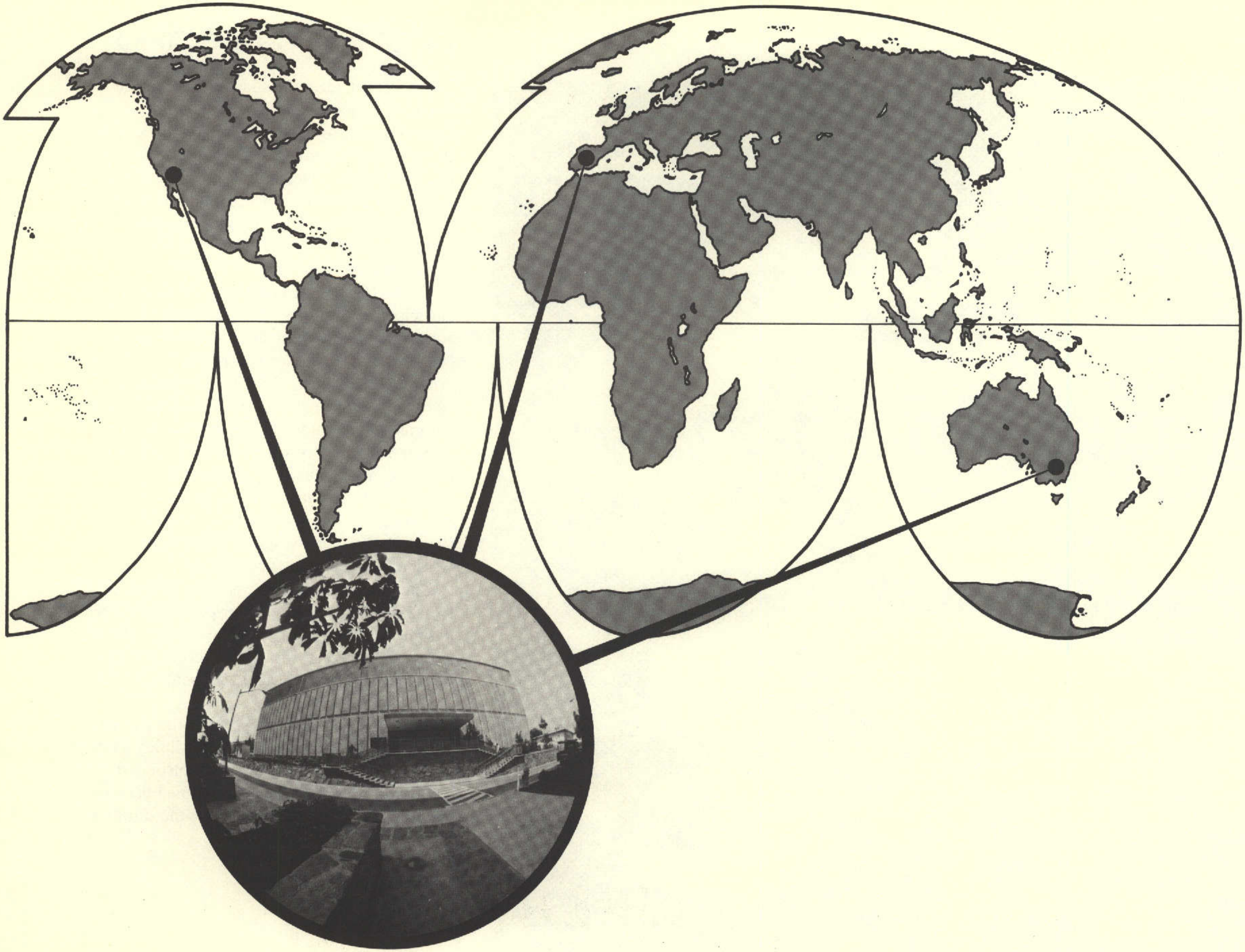
preflight testing

Before a spacecraft is launched from the Kennedy Space Center, many tests are required to ensure a successful flight. Portions of the spacecraft are tested separately and in combination. The complete flight-ready spacecraft is subjected to testing under simulated flight conditions—including the heat, cold, and vibration it will experience—to make certain that it can survive in space.

Meanwhile, a test program is begun for participating facilities of the Mission Control and Computing Center and the Deep Space Network. The standard equipment and computer programs are tested, along with the special equipment and programs developed to satisfy the unique demands of the flight project. The personnel who will operate the equipment and support the mission attend orientation lectures, take training courses, and learn special operating procedures, readying themselves to react calmly, quickly, and accurately under both routine and emergency conditions.

Once the flight mission personnel are trained to use the control center, they participate in tests designed to simulate the actual mission, complete with pre-arranged problems to solve. A high level of proficiency must be achieved before all systems are ready for launch.

After the spacecraft has been successfully launched, full operational responsibility switches to the facilities of the Mission Control and Computing Center, where the trained personnel take charge of the spacecraft for the duration of the flight.



space flight operations

Although the scientific information gathered by a spacecraft may be studied for years after a mission is completed, certain data that reports the spacecraft performance must be scrutinized within seconds after it arrives on Earth. Time is critical because the personnel directing the flight must know, minute by minute, how the spacecraft is functioning as it speeds to its destination. The earlier any problem in the spacecraft or in the ground system can be detected and the malfunction corrected, the less likely it is to compromise the success of the mission. Maintaining such communications with a spacecraft millions of miles from Earth is the responsibility of personnel operating within the MCCC.

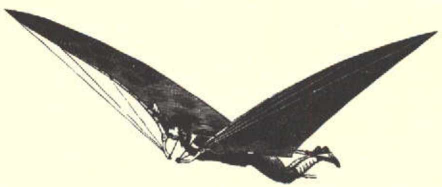
Computers, communications equipment, and operational support areas of the MCCC are contained in two large buildings. From this control center, the flight personnel communicate with a spacecraft by sending messages to one or more of the worldwide tracking stations. A transmitter in the tracking station then relays the message to the spacecraft. The tracking station antenna receives the signals sent back by the spacecraft and relays them to the MCCC.

To determine how a spacecraft is performing, personnel must know where the spacecraft is in space, how fast it is traveling, in what direction it is headed, the condition of its equipment, and whether the equipment is taking the expected scientific measurements. This data, collected at the tracking stations, is transmitted to and processed by the computers into a form that can be interpreted.

Teams of engineers and scientists study different aspects of the flight and continually report their findings to the Chief of Mission Operations. Each team analyzes a different type of data.

The Navigation Team studies tracking data after computer processing has been done. Tracking data, which consists of measurements needed to determine the flight path of the spacecraft, is analyzed to answer such questions as where the tracking station antennas must point in the sky to "see" the spacecraft, how far from Earth the spacecraft is at any given time, and how fast it is traveling in relation to the Earth.

The Science Team, including those in charge of each experiment, studies the data from each science experiment subsystem on the spacecraft. Depending on the flight project and its scientific goals, the science data might include measurements of radiation, magnetic fields, solar flare intensity, and the chemical composition of the lunar or planetary surface; or it might consist of elements of television pictures of the Moon or a planet.



The Spacecraft Team studies the engineering data, which reports the performance of the spacecraft in its deep space environment. Engineering data consists of measurements from each engineering subsystem on board, and provides such information as the temperature of the solar panels, the amount of usable power left in the batteries, the amount of fuel in the tank of the trajectory correction engine, and whether the spacecraft is stabilized in flight.

Each of these teams coordinates activities with the Chief of Mission Operations, who has overall responsibility for project operations. The plans of the Chief of Mission Operations are carried out 24 hours a day by the Command Team, whose members closely watch the displays of spacecraft status and translate these plans into commands sent to the spacecraft.

The MCCC must support several flight projects simultaneously with a centralized data processing capability. Besides providing mission control and computing facilities to flight projects, MCCC buildings house the control center of the DSN. From here, the entire operation of the network is conducted, resources are scheduled, and performance and reliability are studied.

receiving and routing data

The flight data received by the tracking stations is transmitted to the MCCC over high-speed data and teletype circuits. The data is identified on arrival at the communications center in the MCCC as to the type of information it provides and its origin, and its destination is then determined.

The high-speed data (tracking, engineering, and science information) is routed immediately to the computer facilities. The teletype data, which duplicates the high-speed data (at least in part) as a backup data source, is simultaneously printed out and displayed on closed-circuit television monitors throughout the building.

The communications center also provides lines for voice communication. Voice lines connect with the tracking stations; in addition, personnel within the complex can speak with each other on special voice networks, in order to direct, control, and monitor space flight activities.

processing data

In its raw form, data from the spacecraft is received at the MCCC as a string of numbers. The computer facilities translate these numbers into such scientific or engineering terms as power in volts, temperature in degrees, current in amperes, velocity in kilometers per second, and so on. The different types of data are separated and delivered to the appropriate analysis team: Navigation, Science, or Spacecraft. Data is provided either on paper printouts or on a video monitor, or both.

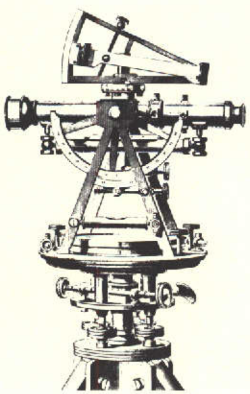
When results of the analysis indicate that adjustment to either the spacecraft or the scientific experiments is necessary, the desired changes are processed in mathematical terms through the same computers, emerging as command instructions. The computer facilities also process and compute data required for the operation of the tracking network. This data includes instructions for pointing the station antennas at the correct angle to pick up the spacecraft signal, information on the performance of the stations, such as signal strength and receiver capability, and information on the network configuration.

displaying data

Computer-processed spacecraft data and network data are displayed in a variety of ways throughout the building, for study by the spacecraft analysis teams and for monitoring equipment performance in the MCCC and at the tracking stations. Data is presented in both real-time and non-real-time displays.

Data display devices include computer printers, cathode-ray tube displays, and video monitors. In addition to these computer-driven devices, many other spacecraft status displays are provided. Some are operated manually and others display information automatically. Many of these displays can be transmitted throughout the building by means of the closed-circuit television system.

By monitoring and interpreting the data received from the spacecraft, the analysis teams not only find and correct problems—they may also detect information that allows them to modify a sequence of scientific experiments on the basis of the results that are being received, in order to use the spacecraft's capability most effectively.

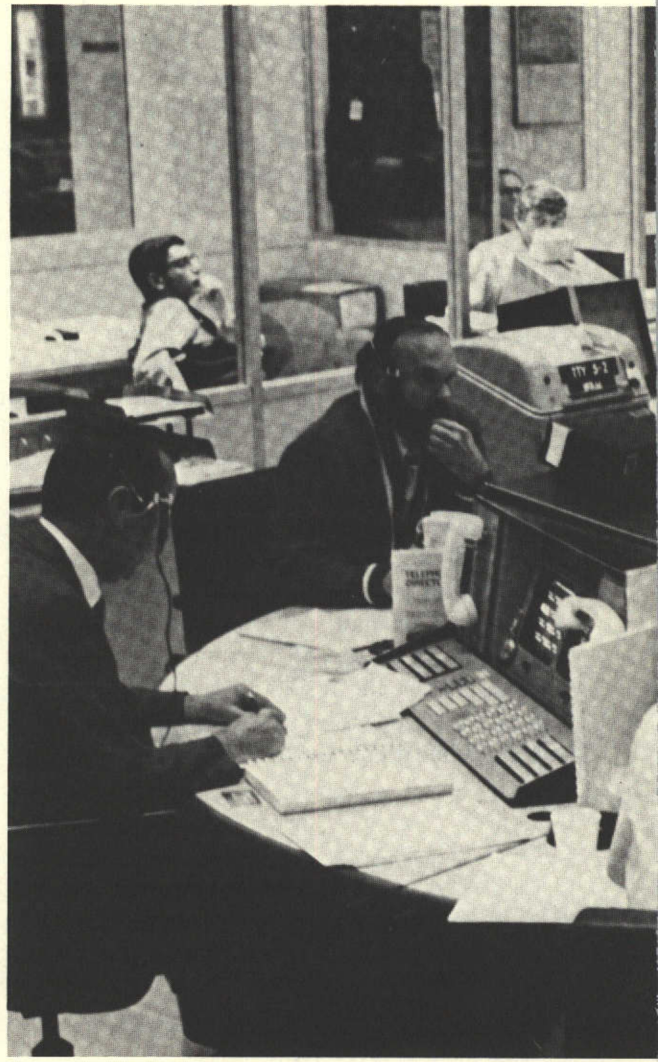


interpreting data

1 The engineers on the Navigation Team study the tracking data continually to refine their computation of the spacecraft's position and determine any requirements for changing its path. The forces affecting the spacecraft, such as gravity, must be taken into account in their calculations. On the basis of their findings, they recommend spacecraft maneuvers to the Spacecraft Team and the Command Team.

2 The performance of each engineering subsystem is monitored by a Spacecraft Team member who is responsible for that subsystem. Because the exact conditions on the spacecraft can rapidly be determined, slight changes in one data measurement can alert a team member to potential trouble. If any engineering measurement exceeds predetermined limits, visible and/or audible alarms are activated.

3 The data from the spacecraft's scientific experiments being returned to Earth are studied by the Science Team. By analyzing the output of special science computer programs, they know from minute to minute what phenomena are being measured. If they see indications of data that may be of special interest, they may request particular science sequences to be performed by the spacecraft.



selecting courses of action

4 At critical times throughout the mission, the Chief of Mission Operations meets with the leaders of the analysis teams to discuss mission problems and to select courses of action that are acceptable to all. This means that no analysis team can start a sequence of commands without the knowledge of the other analysis teams. A solution of one team's problem may create a problem for another team. All the pros and cons must be weighed by the Chief of Mission Operations to determine the best possible course of action.

commanding the spacecraft

5 Some of the commands that direct the spacecraft are stored in the spacecraft's on-board computer before the flight begins. All other commands are sent to the spacecraft from the tracking stations on Earth. The Command Team formulates the command sequences, which are entered into a computer and are then automatically processed and verified as they pass through the network communications to the tracking station and on to the spacecraft.

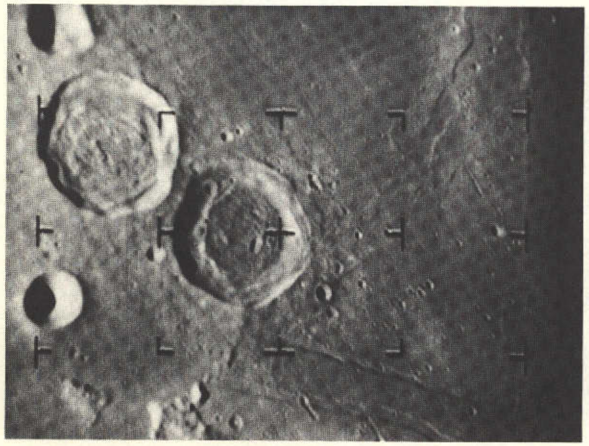
On the spacecraft, the ground commands are received by the radio frequency subsystem and relayed to the flight command subsystem, where they are identified and issued to the appropriate subsystem of the spacecraft.

achievements

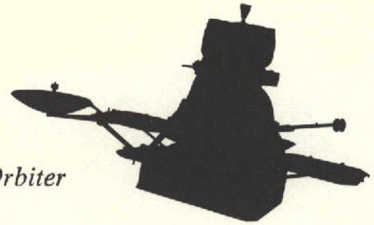
Ranger

As the first series of unmanned flights to the Moon, the Ranger mission produced the world's first closeup photographs of the Moon and led the way for Surveyor and finally Apollo. Ranger greatly increased the growing fund of knowledge concerning celestial navigation and spacecraft design and behavior. Tracking data from Ranger 6 alone reduced by 75% the uncertainty of the known mass of the Earth.

Ranger's most dramatic contribution was 17,267 pictures of the Moon, revealing new facts about the lunar surface. The Ranger 7 camera system yielded high-resolution television pictures with approximately 2000 times better definition than previous Earth-based photography.



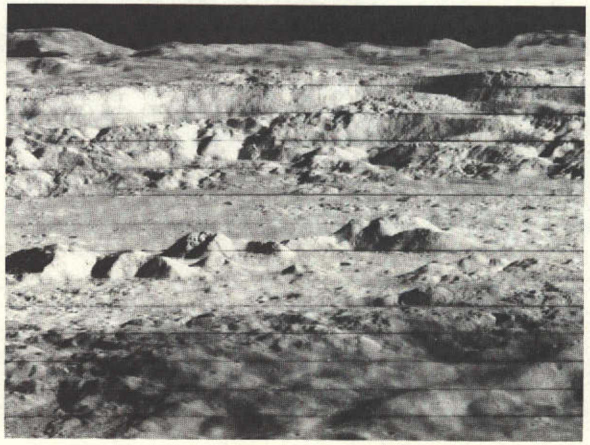
Photograph taken by Ranger 8 at an altitude of 243 kilometers before impact in the Sea of Tranquility.



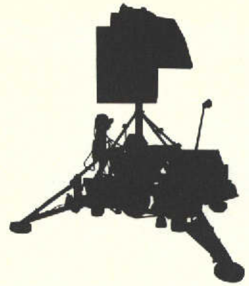
Lunar Orbiter

Scouting of proposed Apollo landing sites was the primary goal of the Lunar Orbiter series of five flights. The scientific rewards from these photographic orbital flights were outstanding: thousands of excellent lunar pictures were returned to Earth. Lunar Orbiter 4 alone photographed 99% of the near side of the Moon and 80% of the far side. Lunar Orbiter 5 provided not only detailed coverage of five Apollo sites and 36 other areas of scientific interest, but also caught a full view of Earth in near-full phase.

Tracking data acquired from the Lunar Orbiter missions have enabled scientists to determine the existence of mass concentrations (mascons) beneath the lunar surface.

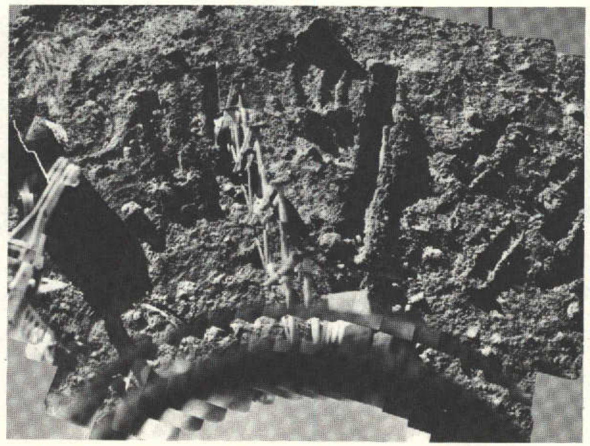


Oblique photograph taken by Lunar Orbiter showing the interior walls of the crater Copernicus.

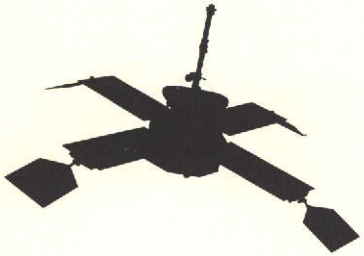


Surveyor

The five successful Surveyor spacecraft soft-landed on the surface of the Moon and sent back information about the lunar surface that was vital to the success of the Apollo manned lunar missions. Perhaps most important, Surveyor demonstrated that the surface of the Moon was strong enough to bear the weight of a spacecraft or an astronaut. Surveyor experiments that studied the physical and chemical properties of the lunar soil included a soil sampler (an extendable, rake-like claw) that was commanded from Earth to dig trenches in the soil, for the study of surface properties. Surveyor sent back more than 65,000 pictures of the Moon.



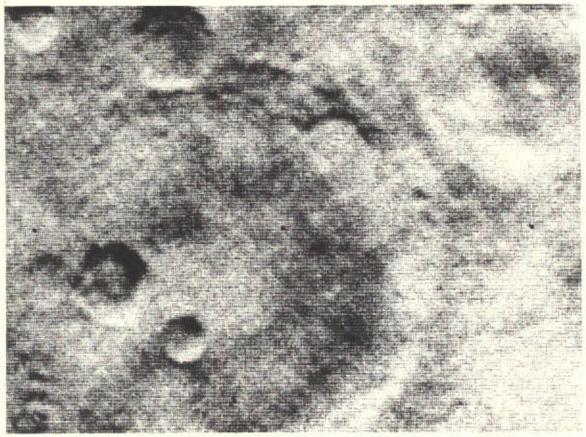
Series of trenches being dug in the lunar surface by Surveyor's soil sampler (composite photograph).



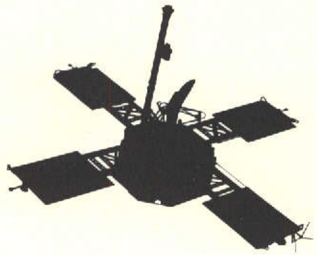
Mariner 4

Mariner 4 was the first spacecraft ever to send back photographs of another planet. From the 22 television pictures of Mars taken by Mariner 4, scientists discovered densely packed, lunar-style craters on the Martian surface, but they could see no evidence of "canals." Altogether, the pictures provided 3.75 million bits of data, a significant improvement over the pictures of Mars available at the time, since even the best of the existing Earth-based pictures of the planet contained only about 10,000 bits of data.

Other experiments yielded valuable information on the chemical, magnetic, and radiation properties of the region surrounding the planet.

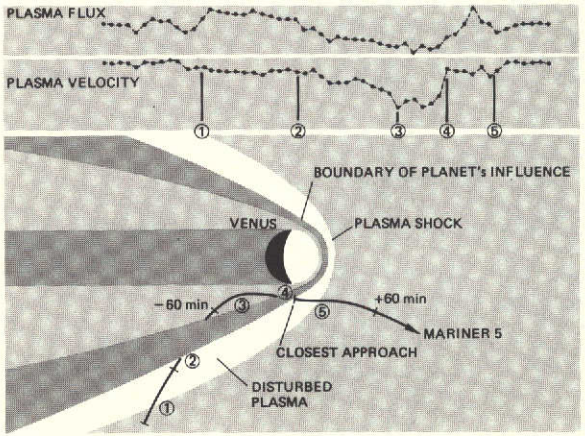


Picture taken by Mariner 4 on its flight past the planet Mars, showing a crater some 120 kilometers in diameter.



Mariner 5

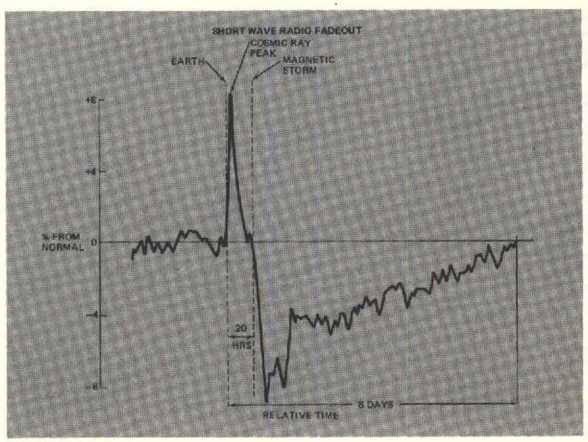
Before the flight of Mariner 5, scientists knew that the planet Venus was surrounded by a dense, cloudy atmosphere, that it had only a weak magnetic field, if any, and that it was very hot. Mariner 5 amplified this knowledge, indicating that the magnetic field of Venus is indeed weak (about 1,000 times less than the Earth's), and that the dense atmosphere of Venus deflects the solar wind, forming a plasma shock wave around the planet. (The solar wind is composed of charged particles constantly streaming out from the Sun.) The atmosphere of Venus is, in fact, so dense that it bent the radio signals of Mariner 5 as they traveled through it; such a dense atmosphere would also bend light rays around the planet, so that one could see the Sun at night on Venus, if the atmosphere were clear enough.



Mariner 5 measurements indicating decreased plasma flux and velocity in the region behind Venus.

Pioneer

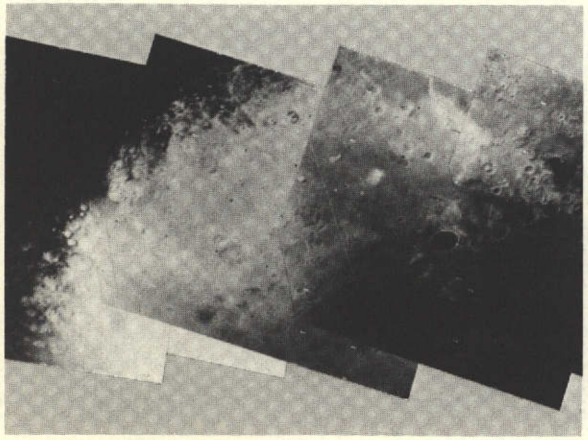
By the end of 1971, Pioneers 6, 7, 8, and 9 (the four Pioneer spacecraft still operating) had completed a total of 230 months of tracked flight and had sent back to Earth almost 20 billion bits of information, which has been received, processed, analyzed, and reported. The measurements collected are related to charged particles, the Sun's magnetic field, and cosmic dust. Scientific discoveries made by Pioneer experimenters include: (1) the presence of helium and argon charged particles in solar plasma, (2) temperature differences in solar plasma, (3) the jump in helium ion content from 4% to 50% during high solar activity, (4) the fact that cosmic rays are not symmetrical, and (5) the fact that the Earth has a magnetic "tail" that is turbulent and flapping.



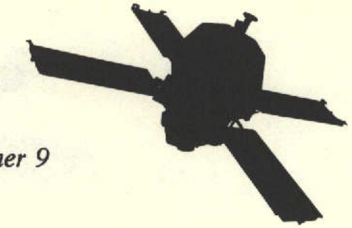
Cosmic ray activity due to a solar flare, as measured by Pioneer on its flight in interplanetary space.

Mariner 6–7

The first successful dual-spacecraft planetary flyby in the U.S. unmanned program was completed by Mariners 6 and 7 in late summer 1969. Precision radio tracking contributed to the outstanding delivery accuracy of each spacecraft to within 320 kilometers of its desired flyby point, following a 320,000,000-kilometer journey to Mars. Many high-quality TV pictures were taken by both Mariners during their approach and flyby phases. Ultraviolet and infrared spectrometers measured the presence of such atmospheric species as atomic hydrogen and oxygen, carbon monoxide and dioxide, traces of water vapor, and such other quantities as ice and dry ice clouds, and indications of suspended silicate "dust" clouds. Infrared radiometer temperature measurements indicated that the south polar cap may consist of frozen carbon dioxide.

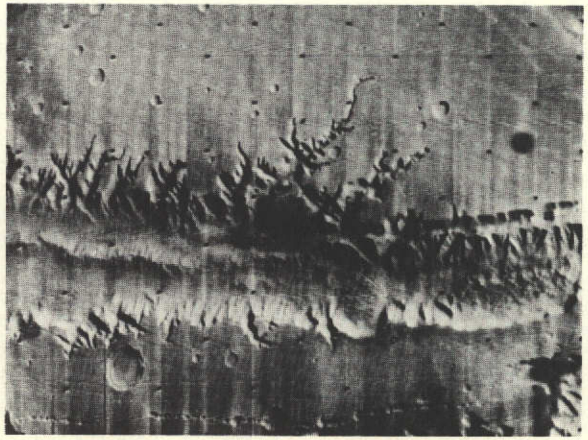


Processed mosaic of the Mariner 6 near-encounter TV pictures of Mars' south polar cap.



Mariner 9

When Mariner 9 arrived at Mars in November 1971, the planet was almost totally obscured by a gigantic dust storm which had raged for several months. Photographic mapping of the surface by the first spacecraft to orbit another planet was delayed six weeks, and science investigators concentrated on the atmosphere while the dust subsided. Post-storm pictures revealed a geologically active planet with volcanic mountains and calderas larger than any on Earth; crevasses several thousand miles long and two miles deep; and evidence of glaciated terrain and heavy layering near the south polar cap. An average of 60 pictures each day were recorded and played back to Earth during Mariner 9's first 3½ months in Mars orbit. During the same period, more than 26,000 commands were generated and transmitted to the spacecraft.



Mariner 9 wide-angle photograph of unique Martian canyon in Tithonius Lacus.

National Aeronautics and Space Administration
Jet Propulsion Laboratory/California Institute of Technology

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